Hot-Gas Filter Testing
with a Transport Reactor Development Unit

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Introduction

The U.S. Department of Energy's Federal Energy Technology Center (DOE FETC) has a hot-gas cleanup (HGC) program intended to develop and demonstrate gas stream cleanup options for use in combustion- or gasification-based advanced power systems. One objective of the FETC HGC program is to support the development and demonstration of barrier filters to control particulate matter. The goal is not simply to meet current New Source Performance Standards (NSPS) with respect to particulate emissions, but also to protect high-efficiency gas turbines and control particulate emissions to levels low enough to meet the more stringent regulatory requirements anticipated in the future. DOE FETC is investing significant resources in the Power Systems Development Facility (PSDF) under a cooperative agreement with Southern Company Services, Inc. (SCS). The PSDF will comprise five modules, including an advanced gasifier module and an HGC module. The gasifier module involves the M.W. Kellogg transport reactor technology for both gasification and combustion (1, 2). Several other demonstration-scale advanced power systems that will also utilize hot-gas particulate cleanup technology will benefit indirectly from this research. These systems include the Clean Coal IV Piñon Pine IGCC (integrated gasification combined cycle) Power Project located at the Sierra Pacific Power Company's Tracy Station near Reno, Nevada.

The transport reactor demonstration unit (TRDU) was built and operated at the Energy & Environmental Research Center (EERC) under Contract No. C-92-000276 with SCS. The M.W. Kellogg Company designed and procured the reactor and provided valuable on-site personnel for start-up and operation. The Electric Power Research Institute (EPRI) was involved in establishing the program and operating objectives with the EERC project team.

The purpose of the previous program was to build a reactor system larger than the Transport Reactor Test Unit (TRTU) located in Houston, Texas, in support of the Wilsonville PSDF transport reactor train. The program was to address design and operation issues for the Wilsonville unit and also help develop information on the operation of the unit to decrease start-up costs.

The TRDU (91–136-kg/hr coal–limestone feed rate) now provides an intermediate scale to the TRTU (4.5 kg/hr coal–limestone feed rate) and the Wilsonville transport reactor (1540 kg/hr feed rate). Some of the design, construction, start-up, and operational issues for the Wilsonville transport train were addressed during this project (3, 4).

Objectives

Research sponsored by the U.S. Department of Energy (DOE) Federal Energy Technology Center (FETC), under Contract DE-FC21-93MC30097 with the Energy & Environmental Research Center, University of North Dakota, PO Box 9018, Grand Forks, ND 58202-9018; fax: 701-777-5181.

The objective of the HGC work on the TRDU located at the EERC is to demonstrate acceptable performance of hot-gas filter elements in a pilot-scale system prior to long-term demonstration tests. The primary focus of the experimental effort will be the testing of hot-gas filter elements as a function of particulate collection efficiency, filter pressure differential, filter cleanability, and durability during relatively short-term operation (100–200 hours). A filter vessel will be used in combination with the TRDU to evaluate the performance of selected hot-gas filter elements under gasification operating conditions. This work will directly support the PSDF utilizing the M.W. Kellogg transport reactor located at Wilsonville, Alabama (5), and indirectly the Foster Wheeler advanced pressurized fluid-bed combustor, also located at Wilsonville (6, 7), and the Clean Coal IV Piñon Pine IGCC Power Project.

Approach

This program has a phased approach involving modification and upgrades to the TRDU and the fabrication, assembly, and operation of a hot-gas filter vessel (HGFV) capable of operating at the outlet design conditions of the TRDU. Phase I upgraded the TRDU based upon past operating experiences. Additions included a nitrogen supply system upgrade, upgraded LASH (limestone ash) auger and coal feed lines, the addition of a second pressurized coal feed hopper and a dip leg ash hopper, and modifications to spoil the performance of the primary cyclone. Phase II included the HGFV design, procurement, and installation. Phases III through V consist of 200-hour hot-gas filter tests under gasification conditions using the TRDU at temperatures of 540°–650°C (1000–1200°F); 9.3 bar; and face velocities of 1.4, 2.3, and 3.8 cm/s, respectively. The increased face velocities are achieved by removing candles between each test.

Project Description

The TRDU is a 91–136-kg/hr (200–300-lb/hr) pressurized circulating fluid-bed gasifier similar to the gasifier being tested at the Wilsonville facility. The TRDU has an exit gas temperature of up to 980 °C (1800°F), a gas flow rate of 590 m^3/hr (340 scfm), and an operating pressure of 9.3 bar (120 psig). The TRDU system can be divided into three sections: the coal feed section, the TRDU, and the product recovery section. The TRDU proper, as shown in Figure 1, consists of a riser reactor with an expanded mixing zone at the bottom, a disengager, and a primary cyclone and standpipe. The standpipe is connected to the mixing section of the riser by a J-leg transfer line. All of the components in the system are refractory-lined and designed mechanically for 11.4 bar (150 psig) and an internal temperature of 1090 °C (2000°F). A detailed description of the TRDU and HGFV design has been given in other reports (4, 8).

The HGFV is designed to handle all of the gas flow from the TRDU at its nominal operating conditions. This vessel has a 1.22-m inner diameter and is 4.7 m long with a refractory inside diameter of 71 cm (28 in.) and a shroud diameter of 61 cm (24 in.). The filter design criteria are summarized in Table 1. Filter vessel design capabilities include operation at elevated temperatures (to 950 °C) and pressures (up to 11.4 bar), with the initial test program operating in the 540 °–650°C range. The HGFV can operate with filter face velocities in the range of 1.25 to 5.1 cm/s. Nineteen 1-meter candles were used in the initial tests, but 1.5-meter candles can be installed in the filter vessel. An existing heat exchanger has been modified to allow for the reduction of the gas stream temperature at the inlet to the filter vessel. An unheated nitrogen backpulse system was constructed to test the effects of backpulsing parameters on candle performance and cleanability. The nitrogen backpulse system was constructed to backpulse up to

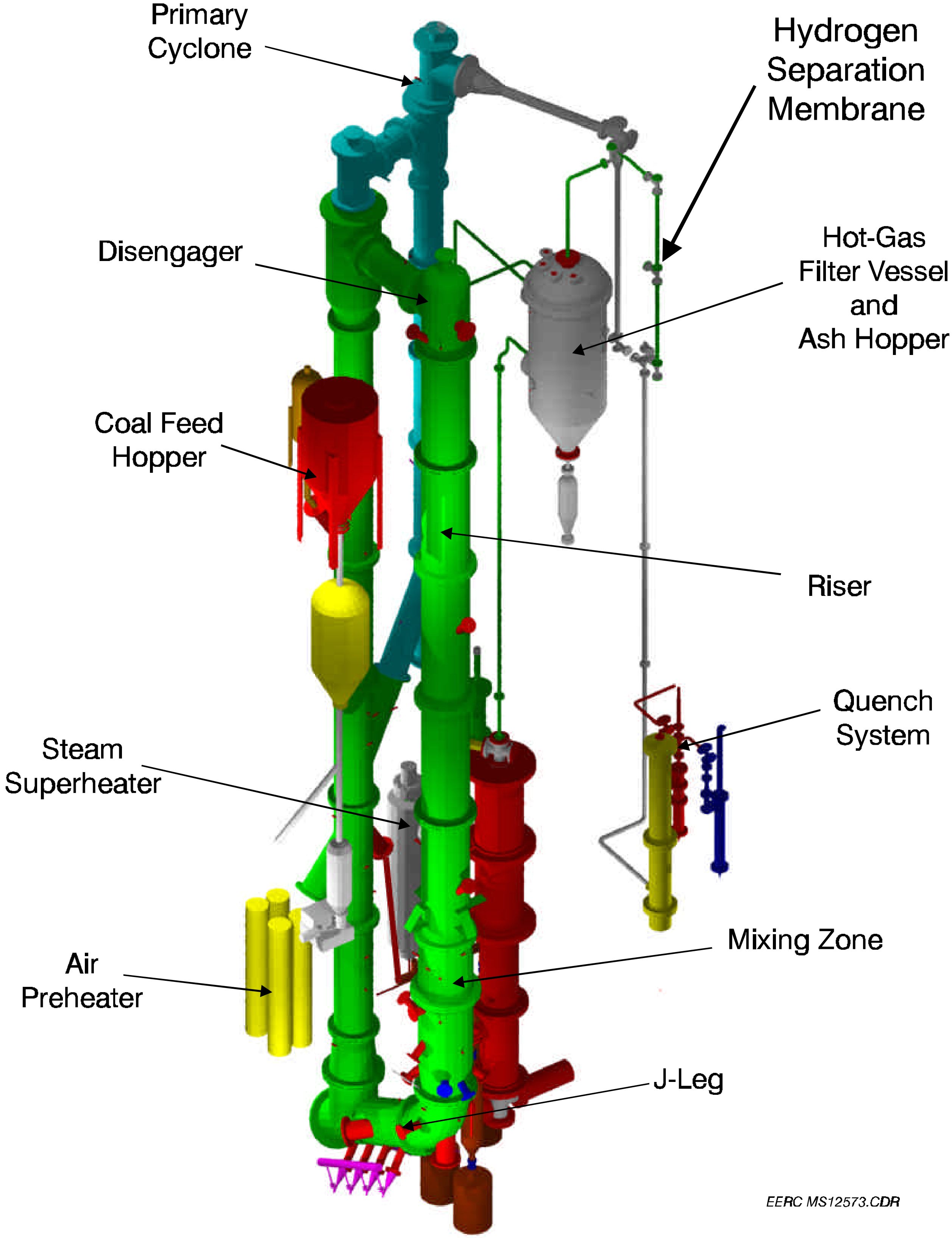

Figure 1. TRDU with HGFV in EERC gasification tower.

TABLE 1

Design Criteria and Operating Conditions for the Pilot-Scale Hot-Gas Filter Vessel

Operating Conditions	Design	Actual
Inlet Gas Temperature	540°–980°C	520°–580°C
Operating Pressure	8.6–11.4 bar	8.3 bar
Volumetric Gas Flow	550 m^3/hr	590 m^3/hr
Number of Candles	19 (1 or 1.5 meter)	13 (1 meter)
Candle Spacing	10.2 cm ℄ to ℄	10.2 cm ℄ to ℄
Filter Face Velocity	1.25–5.1 cm/s	up to 2.3 cm/s
Particulate Loading	<10,000 ppm	< 13,000 ppm
Temperature Drop Across HGFV	< 30°C	25°–30°C
Nitrogen Backpulse System Pressure	up to 56 bar	upto 22 bar
Backpulse Valve Open Duration	up to 1-s duration	up to ¾-s duration

four sets of four- or five-candle filters in a time-controlled or differential pressure-controlled sequence. During this test, the candles were typically pulsed at 87 mbar (35 in. H_2O) pressure drop across the candles. Sample ports for obtaining particulate and hazardous air pollutant (HAP) samples were added to the piping system. A high-pressure and high-temperature sampling system (HPHTSS) was used to extract dust-laden flue gas isokinetically from the TRDU's reducing environment. Details of the HPHTSS are given elsewhere (8). A Fibroplate™ ceramic tube sheet and up to four Fibrosic™ candle filters from Industrial Filter & Pump Mfg. Co., up to seven silicon carbide fiber ceramic candle filters from the 3M Corporation, and up to seven (three iron aluminide and four Vitropore™ silicon carbide) candle filters from Pall Advanced Separations Systems were tested in the filter vessel.

Results

Three test campaigns were conducted during the weeks of October 21–24, 1996; November 13–16, 1996; and February 20–28, 1997. During these weeks, 306 hours of coal feed and 292 hours of gasification were achieved, with the system gases and fly ash passing through the filter vessel during these test campaigns.

The TRDU was operated at two different average temperatures of 825° and 875°C, and little deposition problems were seen in the disengager. Table 2 summarizes the operational performance for the TRDU during these test periods. Coal feed rates ranged from 100 to 177 kg/hr, and the gasifier pressure was 9.3 bar. The dry product gas produced was 6%–7% CO and 8% – 9% H_2, 11%–12% CO_2, and 1%–1.5% CH_4, with the balance being N_2 and other trace constituents. The moisture in the fuel gas averaged 14%. The H_2S concentration averaged 400 to 600 ppm. Calculated recirculation rates ranged from 2000 to 4200 kg/hr.

The HGFV averaged 542°C, with an average temperature drop across the filter vessel of 25° to 30°C. The candles were backpulsed over 2900 times, with no major candle failures. Backpulse operating parameters were an 19.6 up to 23.8 bar reservoir pressure with a ½ or ¾-second full-open time. The N_2 backpulse system and the filter vessel ash letdown system presented no operational problems. The only observed problem was a rapid buildup of pressure drop across the filters resulting in a pulse frequency between 5 to 8 minutes. The average particulate loading going into the HGFV was approximately

TABLE 2

TRDU Actual Operating Conditions

Parameter	P050	P051
Conditions	Gasification	Gasification
Coal	Wyodak	Wyodak
Moisture Content, %	23.3	23.3
Pressure, bar	9.3	9.3
Steam:Coal Ratio	0.26	0.30
Air:Coal Ratio	2.67	2.5
Ca:S Ratio, mole	4.7	4.7
Coal Feed Rate, kg/hr	< 127	< 177
Mixing Zone, °C , avg (min.) (max.) Riser, °C , avg (min.) (max.) Standpipe, °C , avg (min.) (max.)	834 (765) (886) 812 (786) (876) 709 (624) (751)	878 (742) (930) 856 (766) (991) 760 (624) (751)
Conversion, % (excluding dip leg)	90 (97)	93 (97)
Carbon in Bed, %, Standpipe (dip leg)	21 (37)	6 to 15 (15 to 35)
Riser Velocity, m/s	7.6 (10.7)	7.3 to 9.1 (9.75 to 11.6)
Standpipe Velocity, m/s	0.07	0.046 to 0.082
Circulation Rate, kg/hr	2600	1200 to 2000
Duration, hr	71	204
Time	04:30–03:30	15:45–18:45
Date	11-13 to 11-16	2-20 to 2-28

4500 ppm, with a d_{50} of 6 µm, when the primary cyclone was not spoiled and approximately 11,000 ppm with a d_{50} of 12 µm when the cyclone was spoiled. Cyclone spoiling did not appear to have much of an effect on the filter performance or cake permeability. The outlet loading started at 45 ppm and dropped to less than 15 ppm over the course of the test. Carbon in the filter ash ranged from 45% to 60% depending on the conditions. A significant increase in the "cleaned" filter baseline (from ~75 to 210 mbar) was observed over the course of both tests. Off-line cleaning tests were completed which seemed to provide a lower baseline pressure drop when the filters were brought back on-line. However, the rapid rise in pressure drop still occurred. Parameters looked at included time off-line (to reduce reentrainment) and pulse pressure. Time off-line did not appear to have much of an effect; however, higher pulse pressures seemed to provide better results. Figure 2 shows the filter vessel differential pressure and reservoir backpulse pressure. As can be seen, the backpulse interval was becoming very short before we switched to off-line cleaning. After we switched to off-line cleaning, the baseline pressure drop was significantly lower.

Chemical analysis of the particulate samples indicates that mostly the finest-size fraction was coal ash with very little of the silica sand start-up material. Chemical analysis of the TRDU standpipe, dip leg,

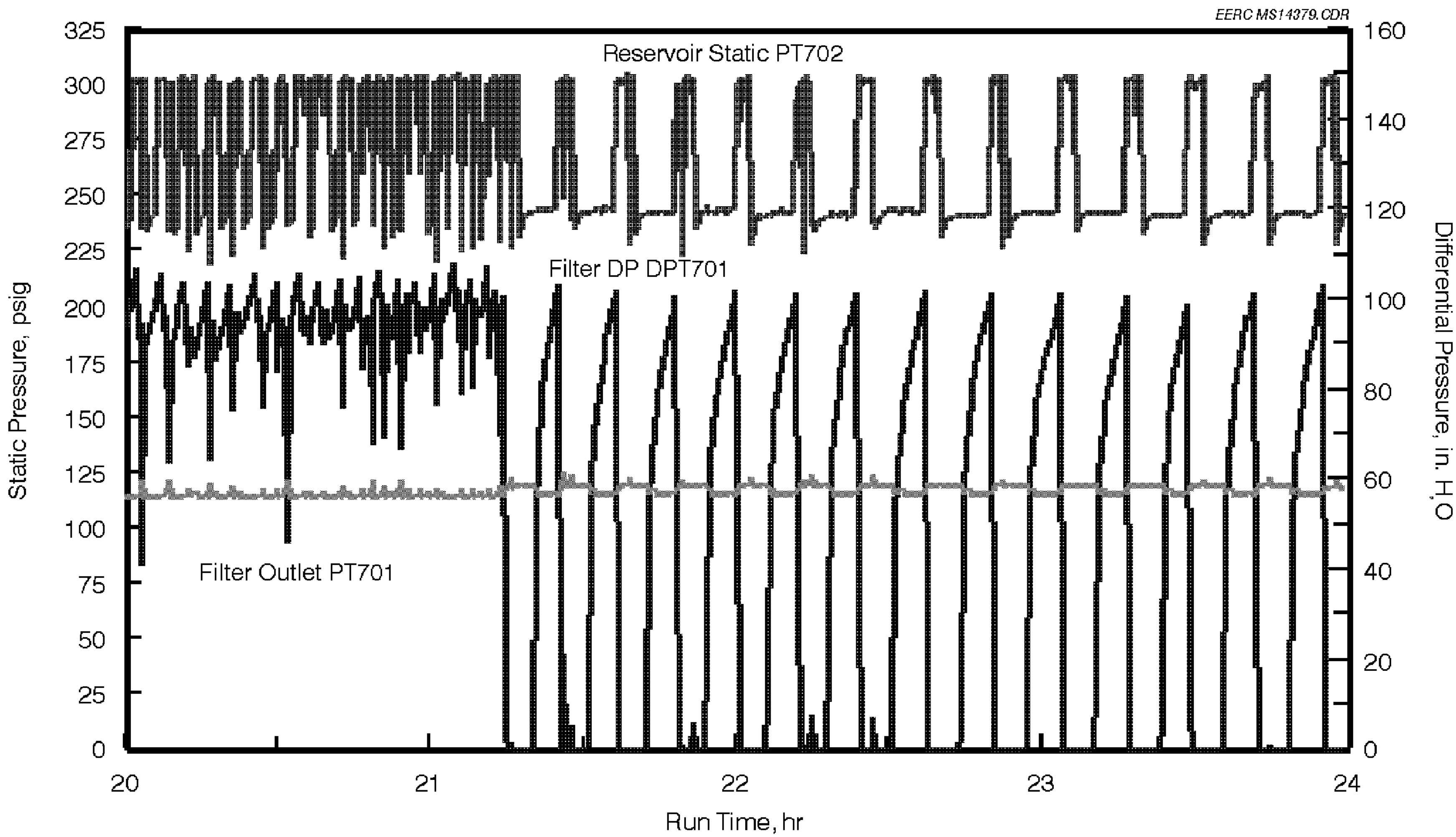

Figure 2. Hot-gas filter vessel pressure for February 1997.

and filter vessel samples indicates that the standpipe material was approximately 80% coal ash, while the dip leg and filter vessel samples were approximately 100% coal ash. The particle-size distributions showed that the standpipe material was getting slightly larger with time, while the dip leg material seemed to be getting smaller and the filter material seemed to stay the same depending upon whether the primary cyclone was being spoiled.

Applications

In addition to direct support for the PSDF at Wilsonville, TRDU operation and filter element testing will benefit other ongoing projects at the EERC. The first sampling and analysis activities were conducted to generate HAP data concerning trace metal transformations, speciation of mercury, and metal concentrations at selected points within the TRDU and HGC in support of a project entitled "Trace Element Emissions" funded by FETC. In addition, materials and ash data concerning the high-temperature filter media and ash interactions were collected and analyzed in support of a project entitled "Hot-Gas Filter Ash Characterization" jointly funded by FETC and EPRI. The exposure of various ceramic and metallic specimens to a gasifier environment has also been a side benefit to this program.

Future Activities

Future plans are to perform HGFV tests using additives to improve the filter cake permeability, improve filter cake release, and minimize filter reentrainment. Other future plans could include piping modifications to allow higher-temperature filter tests (at temperatures up to 900 °C).

Acknowledgments

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